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Comment: Anomalous Anisotropic Light Scattering in Ge-Doped Silica Glass

Saulius Juodkazis,* Shigeki Matsuo, and Hiroaki Misawa
Faculty of Engineering, The University of Tokushima,
2-1 Minamijyosanjima, Tokushima 770-8506, Japan
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An *anomalous anisotropic light scattering* which peaks in the plane of light polarization, the "propeller effect" named by authors, was observed in glass pumped by intense femtosecond laser radiation [1]. A quiver movement of photoelectrons in the light field was the key to an explanation of the effect. A blue emission pattern of a propeller shape was attributed to a defect-related photoluminescence (PL) and explained by its scattering. The emission follows the angular distribution of the photoelectrons given by $\frac{d\sigma}{d\Omega} \propto (1+\cos^2\varphi)$, where the $\frac{d\sigma}{d\Omega}$ is the differential scattering cross section of electrons, φ is the angle between the field amplitude vector $\mathbf{E}$ and the electron momentum $\mathbf{k}_e$.

This is an interesting phenomenon relevant to a fast growing research on the interaction on ultra-short pulses with materials, in particular, with transparent solids. This is a field where some long-lasting controversies over generation of white-light continuum (super-continuum (SC)), self-focusing and dielectric breakdown (DB) mechanisms should be resolved. By this comment we intend to draw attention to the phenomenon of *bremsstrahlung* (German word for "braking radiation"), which escapes proper consideration and can explain, for example, emission spectra of dielectric breakdown and the above mentioned "propeller effect" [1]. In our judgement, the explanation of the "propeller effect" should take into account *bremsstrahlung*, transmission function of a measurement setup, and optical aberrations.

Once the optical excitation generates free electrons, this not only changes the dielectric function, which is usually considered in the SC and light-induced DB mechanisms from the point of view of nonlinear optics, but also inherently causes the light emission due to the *bremsstrahlung*. In a plasma state, after the dielectric breakdown, when free charges are available, the radiated energy, W, per unit angular frequency, ω, in the nonrelativistic case is given by: [2]

$$\frac{dW}{d\omega} = \frac{e^2}{6\pi^2\varepsilon_0 c^3}\left|\int_{-\infty}^{\infty} \dot{v} e^{i\omega t} dt\right|^2, \qquad (1)$$

where $\dot{v}$ is the acceleration of an electron, which has a charge of e, c - speed of light, and ε_0 - permittivity of vacuum. Spectral extent of *bremsstrahlung* depends on the type of electron-ion collisions (Fig. 1) and can be defined as a reciprocal of the collision time τ. In the case of straight-line collisions $\tau^{-1} \simeq v/(2b)$ while for the parabolic ones $\tau^{-1} \simeq (v/(2b))(2b_{90}/b)^2$ [2], v is the velocity of incoming electron. Emission spectrum of *bremsstrahlung* is continuous and spreads from X-rays-to-IR. For an external observer (on z-axis) its spectral content depends on the bandgap of the host material, defects' absorption, PL, fractoluminescence, sonoluminescence, and a transmission function of a measurement setup. Time resolved spectroscopy could, e.g., distinguish among those different contributions. For an isotropic photoelectron distribution in plasma the eqn. 1 defines an emission spectrum integrated over all solid angles.

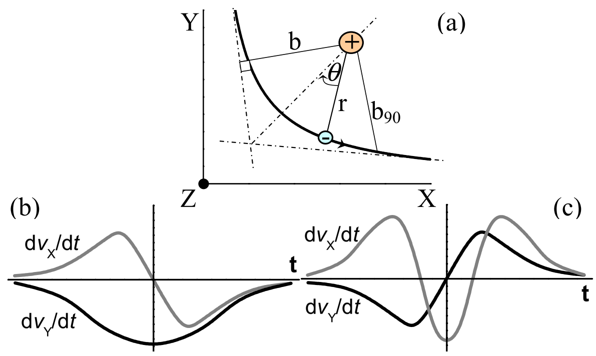

FIG. 1: (a) Geometry of electron-ion collision. Time dependence of acceleration for straight-line, $b \ll b_{90}$, (b) and parabolic $b \gg b_{90}$ (c) collisions (b is the impact parameter; b_{90} is the electron-ion distance at right angle scattering). At $t = 0$ the particles are at the closest.

The actual polarization and angular dependence of the radiation of quiver photoelectrons is defined by $\mathbf{R}\times(\mathbf{R}\times\dot{\mathbf{v}})$ [2], here $\mathbf{R}$ is the vector from the charge to the field point (only a far-field contribution is considered). Figure 1(b-c) qualitatively shows the acceleration projections in the quiver plane of photoelectron oscillating, e.g., along $\mathbf{E}_x$. Obviously, there are considerable accelerations in the perpendicular directions to the $\mathbf{E}_x$ for straight-line and parabolic encounters. *Bremsstrahlung* due to the $\dot{\mathbf{v}}_\mathbf{x}$ will be projected into the $\mathbf{E}_x \propto \mathbf{R}_Z \times (\mathbf{R}_Z \times \dot{\mathbf{v}}_x)$, the quiver direction, for an observer on z-axis ($\overrightarrow{z}$ is usually a direction along the illumination/observation). Thus, the xy-projection of *bremsstrahlung* exactly follows the angular distibution of photoelectrons and explains the "propeller effect".

* Corresponding author; Electronic address: saulius@eco.tokushima-u.ac.jp

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